

# MARICHEV-SAIGO-MAEDA FRACTIONAL OPERATOR REPRESENTATIONS OF GENERALIZED STRUVE FUNCTION

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**ABSTRACT.** The aim of this paper is to apply generalized operators of fractional integration and differentiation involving Appell's function  $F_3(\cdot)$  due to Marichev-Saigo-Maeda, to the generalized Struve function. The results are expressed in terms of generalized Wright function. The results obtained here are general in nature and can easily obtain various known results.

## 1. INTRODUCTION

Recently, Nisar *et al.* [14] introduced a new generalization of Struve function and defined as the following power series:

$${}_a\mathcal{W}_{p,b,c,\xi}^{\alpha,\mu}(z) := \sum_{k=0}^{\infty} \frac{(-c)^k}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} \left(\frac{z}{2}\right)^{2k+p+1} \quad (a \in \mathbb{N}, p, b, c \in \mathbb{C}), \quad (1.1)$$

where  $\lambda > 0, \alpha > 0, \xi > 0$  and  $\mu$  is an arbitrary parameter.

The Fox-Wright hypergeometric function  ${}_p\Psi_q(z)$  is given by the series

$${}_p\Psi_q(z) = {}_p\Psi_q \left[ \begin{matrix} (a_i, \alpha_i)_{1,p} \\ (b_j, \beta_j)_{1,q} \end{matrix} \middle| z \right] = \frac{\prod_{j=1}^q \Gamma(\beta_j)}{\prod_{i=1}^p \Gamma(\alpha_i)} \sum_{k=0}^{\infty} \frac{\prod_{i=1}^p \Gamma(a_i + \alpha_i k)}{\prod_{j=1}^q \Gamma(b_j + \beta_j k)} \frac{z^k}{k!}, \quad (1.2)$$

where  $a_i, b_j \in \mathbb{C}$ , and  $\alpha_i, \beta_j \in \mathbb{R}$  ( $i = 1, 2, \dots, p; j = 1, 2, \dots, q$ ). Asymptotic behavior of this function for large values of argument of  $z \in \mathbb{C}$  were studied in [2], under the condition

$$\sum_{j=1}^q \beta_j - \sum_{i=1}^p \alpha_i > -1, \quad (1.3)$$

was found in the work of [19, 20]. Properties of this generalized Wright function were investigated in [5] (see also [4, 6, 7]).

The familiar generalized hypergeometric function  ${}_pF_q$  is defined as follows [16]:

$${}_pF_q \left[ \begin{matrix} (a_p) \\ (b_q) \end{matrix} ; z \right] = \sum_{n=0}^{\infty} \frac{\prod_{j=1}^p (a_j)_n}{\prod_{j=1}^q (b_j)_n} \frac{z^n}{n!} \quad (1.4)$$

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$$(p \leq q, z \in \mathbb{C}; p = q + 1, |z| < 1),$$

which is an obvious special case of the Fox-Wright hypergeometric function  ${}_p\Psi_q(z)$  (1.2) when  $\alpha_i = 1 = \beta_j$  ( $i = 1, 2, \dots, p; j = 1, 2, \dots, q$ ).

Let  $\lambda, \lambda', \xi, \xi', \gamma \in \mathbb{C}$  with  $\Re(\gamma) > 0$  and  $x \in \mathbb{R}^+$ . Then the generalized fractional integral operators involving the Appell functions  $F_3$  are defined as follows:

$$\left(I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} f\right)(x) = \frac{x^{-\lambda}}{\Gamma(\gamma)} \int_0^x (x-t)^{\gamma-1} t^{-\lambda'} F_3\left(\lambda, \lambda', \xi, \xi'; \gamma; 1 - \frac{t}{x}, 1 - \frac{x}{t}\right) f(t) dt \quad (1.5)$$

and

$$\left(I_-^{\lambda, \lambda', \xi, \xi', \gamma} f\right)(x) = \frac{x^{-\lambda'}}{\Gamma(\gamma)} \int_x^\infty (t-x)^{\gamma-1} t^{-\lambda} F_3\left(\lambda, \lambda', \xi, \xi'; \gamma; 1 - \frac{t}{x}, 1 - \frac{x}{t}\right) f(t) dt. \quad (1.6)$$

The generalized fractional integral operators of the types (1.5) and (1.6) have been introduced by Marichev [11] and later extended and studied by Sagio and Maeda [17]. Recently, Purohit *et al.* [15], Kumar *et al.* [10], Baleanu *et al.* [1] and Mondal and Nisar [13] have investigated image formulas for Marichev-Saigo-Maeda fractional integral operators involving various special functions.

The corresponding fractional differential operators have their respective forms:

$$\left(D_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} f\right)(x) = \left(\frac{d}{dx}\right)^{[\Re(\gamma)]+1} \left(I_{0+}^{-\lambda', -\lambda, -\xi', -\xi + [\Re(\gamma)]+1, -\gamma + [\Re(\gamma)]+1} f\right)(x) \quad (1.7)$$

and

$$\left(D_-^{\lambda, \lambda', \xi, \xi', \gamma} f\right)(x) = \left(-\frac{d}{dx}\right)^{[\Re(\gamma)]+1} \left(I_-^{-\lambda', -\lambda, -\xi', -\xi + [\Re(\gamma)]+1, -\gamma + [\Re(\gamma)]+1} f\right)(x). \quad (1.8)$$

The fractional integral operators have many interesting applications in various fields, for example certain class of complex analytic functions (see [8]). For some basic results on fractional calculus, one may refer to [9, 12, 18].

The following known results will be required (see [17], [6]).

**Lemma 1.1.** *Let  $\lambda, \lambda', \xi, \xi', \gamma, \rho \in \mathbb{C}$  be such that  $\Re(\gamma) > 0$  and*

$$\Re(\rho) > \max\{0, \Re(\lambda - \lambda' - \xi - \gamma), \Re(\lambda' - \xi')\}.$$

*then there exists the relation*

$$\left(I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1}\right)(x) = \frac{\Gamma(\rho) \Gamma(\rho + \gamma - \lambda - \lambda' - \xi) \Gamma(\rho + \xi' - \lambda')}{\Gamma(\rho + \xi') \Gamma(\rho + \gamma - \lambda - \lambda') \Gamma(\rho + \gamma - \lambda' - \xi)} x^{\rho - \lambda - \lambda' + \gamma - 1} \quad (1.9)$$

where

$$\Gamma \left[ \begin{matrix} a, b, c \\ d, e, f \end{matrix} \right] = \frac{\Gamma(a)\Gamma(b)\Gamma(c)}{\Gamma(d)\Gamma(e)\Gamma(f)}.$$

**Lemma 1.2.** Let  $\lambda, \lambda', \xi, \xi', \gamma, \rho \in \mathbb{C}$  such that  $\Re(\gamma) > 0$  and

$$\Re(\rho) > \max\{\Re(\xi), \Re(-\lambda - \lambda' + \gamma), \Re(-\lambda - \xi' + \gamma)\}.$$

Then the following formula holds true:

$$\begin{aligned} & \left( I_{-}^{\lambda, \lambda', \xi, \xi', \gamma} t^{-\rho} \right) (x) \\ &= \frac{\Gamma(-\xi + \rho) \Gamma(\lambda + \lambda' - \gamma + \rho) \Gamma(\lambda + \xi' - \gamma + \rho)}{\Gamma(\rho) \Gamma(\lambda - \xi + \rho) \Gamma(\lambda + \lambda' + \xi' - \gamma + \rho)} x^{-\lambda - \lambda' + \gamma - \rho}. \end{aligned} \quad (1.10)$$

The aim of this paper is to apply the generalized operators of fractional calculus for the generalized Struve function in order to get certain new image formulas.

## 2. FRACTIONAL INTEGRALS OF GENERALIZED STRUVE FUNCTION

**Theorem 1.** Let  $\lambda, \lambda', \xi, \xi', \gamma, \rho \in \mathbb{C}$  be such that  $\Re(\gamma) > 0$  and

$$\Re(\rho) > \max\{0, \Re(\lambda - \lambda' - \xi - \gamma), \Re(\lambda' - \xi')\}.$$

then

$$\begin{aligned} & \left( I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a\mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) \\ &= \frac{x^{\rho+p-\lambda-\lambda'+\gamma}}{2^{p+1}} \\ & \times {}_4\Psi_5 \left[ \begin{matrix} (\rho + p + 1, 2), (\rho + p + \gamma - \lambda - \lambda' - \xi, 2), \\ (\rho + p + 1 + \xi', 2), (\rho + p + 1 + \gamma - \lambda - \lambda', 2), \\ (\rho + p + 1 + \xi' - \lambda', 2), (1, 1); \\ (\rho + p + 1 + \gamma + \lambda' - \xi, 2), (\mu, \alpha), \left( \frac{p}{\xi} + \frac{b+2}{2}, a \right); \end{matrix} \right. \left. -\frac{cx^2}{4} \right]. \end{aligned}$$

*Proof.* Applying the definition of generalized of Struve function, we get

$$\begin{aligned} & \left( I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a\mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) \\ &= \left( I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} \sum_{k=0}^{\infty} \frac{(-c)^k}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} \left(\frac{t}{2}\right)^{2k+p+1} \right) (x), \end{aligned}$$

then on interchanging the integration and summation, we obtain

$$\begin{aligned} & \left( I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a\mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) \\ &= \left( \sum_{k=0}^{\infty} \frac{(-c)^k (2)^{-(2k+p+1)}}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho+2k+p} \right) (x). \end{aligned}$$

Now, for any  $k = 0, 1, 2, \dots$  and

$$\Re(l + \rho + 2k + 1) \geq \Re(\rho + l + 1) > \max \left[ 0, \Re(\lambda - \lambda' - \xi - \gamma), \Re(\lambda' - \xi') \right],$$

we get

$$\begin{aligned} & \left( I_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a \mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) \\ &= \sum_{k=0}^{\infty} \frac{(-c)^k (2)^{-(2k+p+1)}}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} \\ & \quad \times \frac{\Gamma(\rho + p + 1 + 2k) \Gamma(\rho + p + 1 + \gamma - \lambda - \lambda' - \xi + 2k)}{\Gamma(\rho + p + 1 + \xi' + 2k) \Gamma(\rho + p + 1 + \gamma - \lambda - \lambda' + 2k)} \\ & \quad \times \frac{\Gamma(\rho + p + 1 + \xi' - \lambda' + 2k)}{\Gamma(\rho + p + 1 + \gamma - \lambda' - \xi + 2k)} x^{\rho+p-\lambda-\lambda'+\gamma+2k}. \end{aligned}$$

Interpreting the right-hand side of the above equation, in view of the definition (1.2), we arrive at the result of Theorem 1.  $\square$

**Theorem 2.** Suppose  $\lambda, \lambda', \xi, \xi', \gamma, \rho, b, c \in \mathbb{C}$ ,  $a \in \mathbb{N}$  be such that  $\frac{l}{\xi} + \frac{b}{2} \neq -1, -2, -3, \dots$  and

$$\Re(\rho) > \max\{\Re(-\lambda - \lambda' + \gamma), \Re(-\lambda' - \xi' + \gamma), \Re(\xi)\},$$

then

$$\begin{aligned} & \left( I_{-}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a \mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) \\ &= \frac{x^{-\lambda-\lambda'+\gamma-\rho-p-1}}{2^{p+1}} \\ & \quad \times {}_4\Psi_5 \left[ \begin{matrix} (-\xi + \rho + p + 1, 2), (\lambda + \lambda' - \gamma + \rho + p + 1, 2), \\ (\rho + p + 1, 2), (\lambda - \xi - \rho + p + 1, 2), \\ (\lambda + \xi' - \gamma + \rho + p + 1, 2), (1, 1); \\ (\lambda + \lambda' + \xi' - \gamma + \rho + p + 1, 2), (\mu, \alpha), \left(\frac{p}{\xi} + \frac{b+2}{2}, a\right); \end{matrix} \right. \\ & \quad \left. -\frac{cx^2}{4} \right]. \end{aligned}$$

*Proof.* By making use of (1.1) in the integrand of Theorem 2 and interchanging the order of integral sign and summation, which is verified by uniform convergence of the series, we find

$$\left( I_{-}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a \mathcal{W}_{p, b, c, \xi}^{\alpha, \mu}(t) \right) (x) = \left( \sum_{k=0}^{\infty} \frac{(-c)^k (2)^{-(2k+p+1)}}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} I_{-}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho+2k+p} \right) (x).$$

Using Lemma 1.2, we get

$$\begin{aligned}
 &= \sum_{k=0}^{\infty} \frac{(-c)^k (2)^{-(2k+p+1)}}{\Gamma(\alpha k + \mu) \Gamma\left(ak + \frac{p}{\xi} + \frac{b+2}{2}\right)} \\
 &\quad \times \frac{\Gamma(-\xi + \rho + p + 1 + 2k) \Gamma(\lambda + \lambda' - \gamma + \rho + p + 1 + 2k)}{\Gamma(\rho + p + 1 + 2k) \Gamma(\lambda - \xi - \rho + p + 1 + 2k)} \\
 &\quad \times \frac{\Gamma(\lambda + \xi' - \gamma + \rho + p + 1' + 2)}{\Gamma(\lambda + \lambda' + \xi' - \gamma + \rho + p + 1 + 2k)} x^{-\lambda - \lambda' + \gamma - \rho - p - 1 + 2k},
 \end{aligned}$$

which in view of Fox-Wright function arrive at the desired result.  $\square$

### 3. FRACTIONAL DIFFERENTIALS OF GENERALIZED STRUVE FUNCTION

Here we derive the Marichev-Saigo-Maeda fractional differentiation of the generalized Struve function (1.1). The following lemmas will be required (see [3]).

**Lemma 3.1.** *Let  $\lambda, \lambda', \xi, \xi', \gamma, \rho \in \mathbb{C}$  such that*

$$\Re(\rho) > \max\{0, \Re(-\lambda + \xi), \Re(-\lambda - \lambda' - \xi' + \gamma)\}.$$

*Then the following formula holds true:*

$$\begin{aligned}
 &\left(D_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1}\right)(x) \\
 &= \frac{\Gamma(\rho) \Gamma(-\xi + \lambda + \rho) \Gamma(\lambda + \lambda' + \xi' - \gamma + \rho)}{\Gamma(-\xi + \rho) \Gamma(\lambda + \lambda' - \gamma + \rho) \Gamma(\lambda + \xi' - \gamma + \rho)} x^{\lambda + \lambda' - \gamma + \rho - 1}.
 \end{aligned} \tag{3.1}$$

**Lemma 3.2.** *Let  $\lambda, \lambda', \xi, \xi', \gamma, \rho \in \mathbb{C}$  such that*

$$\Re(\rho) > \max\left\{\Re(-\xi'), \Re(\lambda' + \xi - \gamma), \Re(\lambda + \lambda' - \gamma) + [\Re(\gamma)] + 1\right\}.$$

*Then the following formula holds true:*

$$\begin{aligned}
 &\left(D_{-}^{\lambda, \lambda', \xi, \xi', \gamma} t^{-\rho}\right)(x) \\
 &= \frac{\Gamma(\xi' + \rho) \Gamma(-\lambda - \lambda' + \gamma + \rho) \Gamma(-\lambda' - \xi + \gamma + \rho)}{\Gamma(\rho) \Gamma(-\lambda' + \xi' + \rho) \Gamma(-\lambda - \lambda' - \xi + \gamma + \rho)} x^{\lambda + \lambda' - \gamma - \rho}.
 \end{aligned} \tag{3.2}$$

**Theorem 3.** *The following formula hold true:*

$$\begin{aligned}
 &\left(D_{0+}^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a\mathcal{W}_{p,b,c,\xi}^{\alpha,\mu}(t)\right)(x) \\
 &= \frac{x^{\lambda + \lambda' - \gamma + \rho + p}}{2^{p+1}} \\
 &\quad \times {}_4\Psi_5 \left[ \begin{matrix} (1, 1), (\rho + p + 1, 2), (-\xi + \lambda + \rho + 1, 2), \\ (\mu, \alpha), \left(\frac{p}{\mu} + \frac{b+2}{2}, a\right), (-\xi + \rho + p + 1, 2), (\lambda + \lambda' - \gamma + \rho + p + 1, 2), \end{matrix} \right]
 \end{aligned}$$

$$\left( \lambda + \lambda' + \xi' - \gamma + \rho + p + 1, 2 \right); \frac{-cx^2}{4} \Bigg], \\ \left( \lambda + \xi' - \gamma + \rho + p + 1, 2 \right); \frac{-cx^2}{4} \Bigg],$$

provided both the sides exists.

**Theorem 4.** *The following formula hold true:*

$$\left( D_-^{\lambda, \lambda', \xi, \xi', \gamma} t^{\rho-1} {}_a\mathcal{W}_{p, b, c, \xi}^{\alpha, \mu} \left( \frac{1}{t} \right) \right) (x) \\ = \frac{x^{\lambda + \lambda' - \gamma - \rho - p}}{2^{p+1}} \\ \times {}_4\Psi_5 \left[ \begin{matrix} (1, 1), (\xi' + \rho + p + 1, 2), (-\lambda - \lambda' + \gamma + \rho + p + 1, 2), \\ (\mu, \alpha), \left( \frac{p}{\mu} + \frac{b+2}{2}, a \right), (\rho + p + 1, 2), (-\lambda + \xi' + \rho + p + 1, 2), \end{matrix} \right. \\ \left. \begin{matrix} (-\lambda' - \xi + \gamma + \rho + p + 1, 2); \\ (-\lambda - \lambda' - \xi + \gamma + \rho + p + 1, 2); \end{matrix} \frac{-cx^2}{4} \right],$$

provided both the sides exists.

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